P-1836 IT

(54) Title: A METHOD FOR ERROR REDUCTION IN LITHOGRAPHY

WO 00/72090 A2

(57) Abstract: The present invention relates to a method and a system for predicting and correcting geometrical errors in lithography using masks, such as large-area photomasks or reticles, and exposure stations, such as wafer steppers or projection aligners, printing the pattern of said masks on a workpiece, such as a display panel or a semi-conductor wafer. The method according to the invention comprises the steps of collecting information about a mask substrate, a mask writer, an exposure station, and/or about behaviour of a processing step that will occur after the writing of the mask. Further the method comprises predicting from the combined information distorsions occuring in the pattern, when it is subsequently printed on the workpiece; calculating from said prediction a correction to diminish said predicted distorsion, and exposing said pattern onto said mask substrate while applying said correction for said distorsions.

A METHOD FOR ERROR REDUCTION IN LITHOGRAPHY

Field of the invention

The invention relates to production and precision patterning of photomasks and use of such photomasks in microlithography, for example in the production of flat panel displays and semiconductor circuits. Errors in the pattern on the display panel or semiconductor chip can be separated into errors from systematic sources, from the interaction of maskblank and pattern with the equipment, and from random fluctuations. The invention relates to the reduction of these errors. In a different sense the invention relates to the characterization of the photomask substrate and the equipment and processes used with a photomask, the storage and retrieval of information obtained by such characterization, and the generation of corrections to be applied at the time of writing the photomask in order to reduce imperfections in lithography using photomasks.

Background

The development of semiconductor lithography has been exponential since the early 60ies and the produced features are getting smaller every second or third year, at the same time as the circuits get faster and more complex. Figure 1 shows an industry projection of the development for some years forward. Of course the predictions are less certain the farther into the future we look and nobody knows if the electronics industry will still be using transistors in the year 2020. For the next 10 years the projections are more certain and the main uncertainty relates not to "How small?" but to "Exactly when?".

The errors in lithography can broadly be classified as placement and size errors, or "registration" and "critical dimension", ("CD") in the jargon of the trade.

2

There is a more or less fixed relation between the errors
that can be allowed in the pattern and the size of the
smallest features in the pattern. A rule of thumb is that
on the mask the placement of figures has to be within 5%
5   of the design rule and the size of the features should be
within 2.5%. These are surprisingly small numbers, but
have been justified by both theory and experiments. Fig-
ure 1 also shows the necessary registration and CD (size)
control on the mask for each year, assuming that 4X masks
10   will continue to be used. It is seen that the errors are
now 1999 in the low tens of nanometers and will in less
than 15 years be ten times smaller. At the same time then
chips will be larger which means either larger masks or
less reduction. Either way it will be difficult to
15   achieve the needed pattern fidelity.

The invention devises a new general method to reduce
errors in the lithography in order to achieve total er-
rors that are consistent with the projected lithography
development. An important application is for the reduc-
20   tion of clamping errors, being both an important error
source and a good example of errors caused by the inter-
action of several factors.

Clamping errors

25   When a glass plate is held it is deformed by the
holding device and by its own weight. Furthermore, it can
also be distorted by the built-in stress in surface films
deposited on it and by the patterning of said films.
Semiconductor masks are typically 152 x 152 x 6.25 mm and
30   the patterned area may be 127 x 127 mm. Figure 2b shows
how the bending of a plate 201 under the force of gravi-
tation causes the upper area of the glass to contract.
When the plate is released, e.g. held vertically, it
springs back to its natural shape, shown in fig 2a, and
35   contraction disappears. If a pattern was written on the
plate while it was bent, the pattern will be stretched
after relief. Figure 3 shows a diagram with the resulting

maximum error when a plate is supported along two oppo-
site edges, as in fig 2. Here, the expected lateral posi-
tion error is shown as a function of the thickness of the
plate and the size, i.e. the distance between the two
5   supported sides. The interesting conclusion from Figure 3
is that the magnitude of errors that can result from in-
appropriate support of a glass plate is in order of mag-
nitude larger than what is allowable in a high-end mask.
Point A shows a standard semiconductor reticle 152 x 152
10   x 6.25 mm and the maximum deviation is around 400 nm.
Point B is the new standardised mask format 225 x 225 x 9
mm and, despite the fact that the glass plate is thicker,
the deviation is above 1 μm. Point C finally illustrates
that for large-area masks the problem is even worse: an
15   800 mm plate 8 mm gives a possible error of 60 μm. It is
also seen from Figure 3 that increasing the thickness of
the glass plate is a weak remedy. It is impossible to in-
crease the thickness of the 800 mm plate to bring the er-
ror down to 0.1 μm. The same is valid for the 225 mm mask
20   in B: even a glass cube with the side 225 mm has devia-
tions larger than 10 nm.

I conclusion Figure 3 shows the magnitude of the
gravitational deformation and it shows how everything be-
comes more difficult for larger mask sizes.

25

Other errors

Clamping deformation gives a placement or registra-
tion error. Another large source of placement errors in
the finished product is the distorsion in the exposure
30   tool, be it a wafer stepper for semiconductors or a pro-
jection aligner for display panels. The maskwriter has
stage errors, but these are usually well controlled after
calibration to a xy metrology system, such as those made
commercially available by Nikon and Leica. The placement
35   can also be affected by processing, both because films
deposited on or removed from a workpiece have built-in
stress and deform the workpiece, and because some process

steps cause a shrinkage or warping of the workpiece, e.g. high temperature annealing steps. An important source of errors is the pellicle used on masks. Fitting the frame to the mask plate causes the mask plate to bend.

5   Other effects make the size of the pattern features come out differently at different location on a mask or on a chip or display panel. There are several possible mechanisms behind this: uneven focus, non-uniform developer agitation, non-uniform photoresist thickness, uneven

10 chrome properties on the mask and uneven film thickness on a wafer or panel, exposure dose variations in the exposure tools, effects of the time between the exposure and development or between resist coating and exposure and effect from non-perfect pre-exposure and post-

15 exposure baking procedures. Size errors also occur because of the basic imaging properties of mask writer and the exposure station. In particular small features tend to come out too small due to finite resolution and features are affected by the presence of other features in

20 the neighbourhood due to stray exposure. These types of size errors are also intimately coupled to shape errors, such as shortening of line ends and rounding of corners. The exact details of the mask and wafer exposure tools also interact with the pattern and create for example

25 grid snap effects, and spurious pattern features.

Mix and match

The term used in the mask industry is "registration" which really means misregistration from a reference grid,

30 normally an ideal mathematical grid. In the past registration of the finished product to an ideal mathematical grid has not been necessary. If all layers (approximately 25 in a semiconductor chip and 6 in a TFT) are printed using the same type of exposure station systematic and

35 equal behaviour of the exposure stations will cancel, since every layer is distorted in the same way.

However, when resolution is pushed in order to
achieve circuit speed and packing density the cost of li-
thography is rising rapidly, both because of higher tool
cost and because of more expensive masks. To make produc-
5 tion economical the display and chip manufacturers are
trying not to use more sophisticated technology than
needed for each layer, so called mix-and-match. Different
layers can be printed using different types of exposure
tools with different error characteristics. Furthermore
10 the masks may be of different type, e.g. phase-shifting
masks for one layer and standard binary masks on another
layer. The different types of masks may require them to
be written on different maskwriters.

The management of errors is made more complicated by
15 the fact that the exposure tools for critical and non-
critical layers may not even have the same exposure
field. Figure 4 shows dies formed on a semiconductor wa-
fer using tools with different fields. The critical lay-
ers like the transistor layers are printed with a tool
20 that has a field that accommodates only one die, Figure
4a. Less critical layers, such as the top metal layers,
are printed with a different stepper having a larger
field and possibly a different mask reduction factor,
Figure 4b. One or both of the layers can be exposed by a
25 step-and-scan tool, and if both use step and scan they
may very well have the scan direction at right angle to
each other. Furthermore, it is anticipated that in the
future a single die will be exposed in two or more scan-
ning strokes using a so called stitching scanner, Figure
30 4c.

In the past the thinking has been that the masks
should be as close to perfect, i.e. as close to the ideal
mathematical grid, as possible. Then the masks for dif-
ferent layers can be written on different types of mask-
35 writers or even by different mask making companies for
best economy and logistics. When all masks are exposed on
the same stepper, or on steppers of the same type, the

systematic errors in the stepper will largely cancel. This breaks down in the mix-and-match scenario of Figure 4a-c. The only straightforward way to resolve the complicated overlay properties of layers printed in different

5 ways is to make each layer print an image that is close to the mathematically ideal.

The invention gives a method to predict the printing errors in a specific exposure station and correct it beforehand by predistorting and prebiasing the pattern in

10 the opposite sense. In this application is described a practical method to manage the lithographic errors al the way to the finished product, and also in the presence of non-ideal mask blanks and clamping structures.

15 Object of the invention

It is therefore an object of the present invention to provide a method for predicting and correcting geometrical errors in lithography in order to achieve an improved precision.

20 This object is achieved with a method according to the appended claims.

Brief summary of the drawings

Figure 1 gives a projection of future lithography

25 and the requirements on placement (registration) and size (CD). . . . .

Figure 2a shows a plate, e.g. a mask substrate. Fig 2b shows the same plate supported at two sides and the contractive stress above and the tensile stress below the

30 neutral layer which keeps its length when the plate is bent. Fig 2c shows the lateral displacement resulting from a bent plate and how it is related to the dz/dx of the surface.

Figure 3 shows the maximum lateral displacement in

35 the arrangement of Figure 1b as a function of plate size and thickness. The shaded areas show the resulting error.

Figure 4a-c shows dies formed on a semiconductor wafer using tools with different fields, so called mix-and-match lithography.

Fig 5 shows schematically a control method according to the invention.

Fig 6 shows flow chart describing the development of models and how the models are used to predict and correct errors.

Fig 7 shows the control method according to fig. 5 more in detail.

Fig 8 shows how the plate and/or the pattern is affected by different types of errors.

Fig 9 shows a typical implementation of an error correction system suitable for the invention using both pattern modification and writing hardware control.

Fig 10 is a schematic view of a system according to one embodiment of the invention.

Fig 11 is a schematic flow chart of the method used in the system according to fig 10.

Fig 12 is a schematic view illustrating the correction in the embodiment in fig 5 in more detail.

Description of the invention

The invention is best described as a control system, such as is shown in Figure 5. The pattern picks up errors 501, 502 of different kinds when it is converted from a design data file 503 and a mask blank 504 to a mask 505 during a mask writing procedure 506, i.e. exposure, by means of a mask writer 507. The mask is thereafter used to produce an electronic device 508. The pattern file describes what the chip or panel designer wants to see printed and any deviation is to him an error. One part of these errors is that systematic and other errors are different from one time to another. The invention is based on the identification of different types of errors and the appropriate way to reduce each type. Errors that can be found in the output from the system and identified to

be recurring in a systematic fashion are reduced by feed-
ing an inverse error 509 back to the writing of the mask.
This is the feed-back loop 510 in Figure 5. The feed-back
can be pseudo-continuous, i.e. corrections are made after
5 each written mask, or intermittently. The error is meas-
ured by a measuring means 511, and a filter 512 is useful
to keep the feed-back from fluctuation with the noise
component of the measured error. The low-pass filter 512
can use a very simple procedure: use the average of five
10 measurements over five days for setting the first feed-
back, then change it only when the running average over
five consecutive measurement are outside of predetermined
tolerance interval. On the other hand it can be based on
more sophisticated statistics such as time series estima-
15 tions and feed back an appropriately filtered correction
for each measurement of the output errors. More elaborate
statistics can be used to cancel slow changes in the
properties of the total system without ever producing a
rejected part, or to extract error components with dif-
20 ferent characteristics. A statistician skilled in the art
can set up statistical process control (SPC) procedures
that tunes the system without interrupting the production
flow.

In fig 12 the correction system provided in the em-
25 bodiment described above with reference to fig 5 is il-
lustrated in more detail. Input data is transferred to a
data collection unit 1201 in the error reduction system
506. As will be described more in detail in the follow-
ing, such input data could be one, or preferably several,
30 and most preferably all, of the following: pattern (de-
sign) data, blank data mask writer data, exposure tool
data, process data and metrology tool data. The input
data is then forwarded to a data validation unit 1202,
where the data is validated. The validated data is then
35 transferred to error prediction unit 1203 comprising a
model, for a statistical estimation of model parameters.
Correction data is then output as a position correction

map 1204 and/or a correction size map 1203, for correction of pattern element position and pattern element size, respectively.

The correction maps are forwarded to the mask writer
5   507. One or both of the correction maps could be forwarded to the data path 1206 in the mask writer 507 for correction of the data provided from the pattern data file, and thus correcting said distorsion. The altering of the input design data could hereby preferably be made
10 in at least one processor, and preferably in several such processors. Alternatively, or as a complement, the position correction map could be forwarded to the position servos 1205 controlling e.g. the support table supporting the mask substrate during the writing process. In this
15 case, the correction map implies a correction of the position control for the servo system, and thereby the position of the pattern on the substrate. Alternatively, or as a complement, the size correction map could be forwarded to an exposure dose control 1207, such as a dose
20 modulator. Hereby, a correction of the dose according to the predicted correction map could be provided during the exposure.

There are in principle four driving forces for errors: the physical properties of the substrates on which
25 the patterns are printed, i.e. the mask blanks and the wafers or panels, the position on the substrate, the exposing equipment (which can be using electromagnetic radiation or particle beams as the exposing medium) including exposing sequence and environment, and the pattern
30 itself. These driving forces interact with each other directly of via the production processes to create errors. An important feature of the invention is the use of models to translate measured or previously known physical parameters to a placement, size or shape error to be corrected.
35 rected. An example is a plasma etcher. The plasma is non-uniform towards the edges of the substrate and in local areas where the surface exposed to the plasma is differ-

ent from other places in the pattern. This creates a po-
sition- and pattern-dependent size error. It can however
be characterised with a small number of parameters, such
as an edge fall-off magnitude and typical length, and a
5 sensitivity and disturbance length for pattern varia-
tions. Using this model with four parameters it is possi-
ble not only to precompensate for the edge fall-off,
which is equal from plate to plate, but also for the lo-
cal variation which vary with the patterns.

10   Using a model-based error prediction makes it possi-
ble to account for a large number of different error
mechanisms with a manageable amount of empirical data
collection. Designing sampling and measurement plans that
effectively fit the parameters of a model from a limited
15 number of measurements is known in the art, and can be
found in textbooks on experimental design. It is also
known how to design plans to separate between different
driving forces. The ideal situation is that measurement
are made non-destructively on production masks and wa-
20 fers, but for a specific model it may be more efficient
to use a special monitor substrate, i.e. to be able to
distribute a matrix of test structures over the entire
surface.

        The model-based error prediction is further de-
25 scribed in Fig 6. Two different mechanisms for generation
of errors are set up, e.g. edge falloff and pattern de-
pendent etch activity in an etch step. A measurement is
designed which can find the parameters for each and sepa-
rate between them. In this example it can be measuring
30 features in areas with three densities each at three lo-
cations, inside, intermediate, and close to the edge of
the substrate. The measurement is done and the parameters
extracted. Before writing and correcting a pattern rele-
vant information has to be collected in this case the
35 pattern density in different areas of the pattern and the
distance of pattern areas to the edge of the substrate.
The total correction is generated, in most cases by su-

11

perposition of the corrections for the two mechanisms, other times by a more complicated summation.

Another aspect of model-based error correction is shown in Figure 8, namely decomposition of complicated error behaviour into a set of independent and computable error mechanisms. The general geometrical error in a mask writer is very complicated, but it can be decomposed into isotropic expansion, built-in shape, gravitation sag, clamping deformation due to non-ideal geometry of the clamping structure, and interaction between the built-in shape and the clamping geometry. If each error is small, which is the case for lithographic substrates, the contributions can be superposed. On top of it come the stage errors, i.e. errors in the coordinate system of the writer.

An important case of model-based error correction is when a chip has a CD error towards the edge, for example due to stray light. If a 0.18 feature is 3% percent too small one would expect that a + 3% size correction in the mask would compensate it perfectly. However, due to the finite resolution of a stepper there is a more complicated function relating size on the mask to size on the wafer, the so-called "Mask Error Enhancement Factor", MEEF. The enhancement factor is size dependent and depends on the details of the tools and process. Therefor a model need to be used that takes the MEEF into account, and the corrections will not be correct until the MEEF model has been verified a couple of turns around the feedback loop.

Process errors 502, if they can be held constant, can in principle be corrected with the feedback loop. Other errors 501 are impossible to correct by feedback, because they are not constant in time. In the invention one important such error has been identified as the clamping distortion of the mask in the mask writer, the metrology system and in the exposure station that uses the masks. At first sight the clamping errors seem uncon-

trollable, but we have found that they can be predicted from accurate geometrical data for the mask blank itself and the clamping structure of equipment using or operating on the mask. Another seemingly random error source

5   that is controlled in another embodiment of the invention is variations in linewidth due to variations in resist and chrome properties over the mask substrate. Using the invention it is possible to set up and apply models for how the resist thickness and chrome properties affect the

10   feature size of the pattern and correct for the errors created.

Since these properties are possible to measure by measuring means 513, 514 prior to the writing of the mask, it is possible to predict the errors and correct

15   them at the time of writing the pattern, the feed-forward correction loop 515 in Figure 5.

Residual errors

By the feed-forward or feed-back correction 509, or

20   especially a combination of the two, a large portion of the total errors can be controlled and corrected. The residual errors are due to random errors during maskwriting, exposure and processing, and have to be addressed as such, i.e. by better temperature control, vibration-

25   insulation, process automation, etc. They are also due to incomplete error models and uncertainty in the model parameters. We believe that when the framework of the invention is established there will be a development of better and better models until eventually all but the

30   genuine noise errors are removed. The development of models and software for their characterisation and use could well become the mission of independent commercial companies.

A flow chart describing the development of models

35   and how the models are used to predict and correct errors is given in fig 6.

13

A comprehensive list of error sources

Figure 7 shows the work flow from glass block and
CAD file to a finished chip or TFT display, and important
error mechanisms that can be modelled and corrected. The
5   work flow is divided in three separate parts of making
the mask blank, writing the mask on the blank, and fi-
nally using the mask for lithographic production, and
each part is divided in several different steps. For each
step is further indicated different types of errors pos-
10 sible to occur during said step. These errors are however
merely examples of errors possible to occur during each
step, and many other errors are probably possible as
well. As is described above, errors in at least some of
the steps are measured and used either in a feedback or a
15 feed-forward loop to predict the error in the written
pattern, and to generate corrections to compensate for
said predicted errors during the exposure step in the
mask making.

20   _Correction of clamping errors_

If is held in exactly the same way during writing
and use there is no error. Until now it has been possible
to treat the semiconductor mask as a stiff plate with no
deformation induced by clamping, provided that the clamp-
25 ing has been done carefully. There are two developments
that make the clamping-induced deformation more critical
in the future: increased mask size and dramatically
tightened precision requirements. The new mask format of
225 x 225 x 9 mm has been defined and the allowable geo-
30 metrical errors in a mask will be 30 nm in 2001 and below
10 nm a few years later. The registration error allowed
is typically 5% of the features on the photomask and the
error of critical dimensions (CD) must be less than 2.5%.
Current plans for lithography predict that the features
35 will be around 25 nm in the year 2010. With a reduction
ration of 4 the features are 100 nm on the mask and the
registration requirement is then 5 nm and the CD toler-

14

ance 2.5 nm. A few years later the requirements are pre-
dicted to be sub-nanometric if the march toward smaller
scale were to continue. Mask production following what is
known in prior art cannot produce masks to these require-
5   ments. In the invention methods are devised that can re-
duce many systematic errors by an order of magnitude or
more.

It is known in prior art to support the glass plate
at three points. With three supports there is no bending
10   induced by the supports. Therefore it deforms only under
gravity. It is also known to correct the pattern geometry
for the computed deformation due to the gravitational sag
when it is supported on three supports. The deformation
depends only on the plate size and its material proper-
15   ties and can be computed beforehand.

In flat panel production the masks may be 600 x 800
x 12 mm. It is not possible to support such a large plate
on three points and get a sufficiently flat surface. The
plate needs to be supported at more than three points and
20   becomes kinematically over-constrained. The supporting
structure will introduce deformations if the points are
not in a perfect plane. In this case the deformation is a
combination of gravitational sag and deformation due to
the support structure. The same applies to a co-ordinate
25   measuring machine where the plate needs to be measured
without distorsion.

The basic problem is that due to technical con-
straints different machines producing and using a pat-
terned workpiece hold the workpiece by different meth-
30   ods,: For example a reflection-type metrology system for
semiconductor reticles normally uses a three-point sup-
port with the support points chosen for minimum deforma-
tion, but the stepper using the reticle must support it
along the edges to keep the patterned area unobstructed
35   for the exposing light.

If the workpiece or the clamping structure is non-
ideal, i.e. non-flat, the different types of clamping in

different types of equipment give an uncertainty in the
geometry of the workpiece.

     A numerical example: assume that a standard semicon-
ductor reticle (152 x 152 x 6.25 mm) is supported at the
5   four corners. One of the corners is 1 μm out of the plane
of the other three corners, either because the glass is
non-flat or the supporting points are skewed. The bending
of the glass causes a line along one diagonal of the
plate to be stretched and the other diagonal to be com-
10   pressed. This is the same as an orthogonality error in
the pattern on the mask with a maximum lateral position
error on the plate of 0.5 μm * 6.25/2 mm / 152 mm = 20
nm. The error from the clamping must be added to other
error sources such as drift, scale errors and effects
15   from the process. Therefore 20 nm is unacceptable as an
error from the clamping alone. And if the points were lo-
cated closer together or if there were more than four
constraining points the errors would be even larger. We
have found that supporting a plate on four well chosen
20   points is exceptionally good for large plates, giving a
deflection that is 20 smaller than with htree support
points. The invention makes it possible to use four
points and compute the effect of the plate being overcon-
strained. If the flatness in force-free state is known
25   and the height of the upper surface is measured at the
four point one has all necessary information to correct
the pattern for bending and gravitation.

     The invention devises a method for complete predic-
tion of the clamping errors as well as partial correction
30   for stress-induced errors in a multi-machine environment
with equipment for writing masks, printing panels or wa-
fers from masks and metrology systems for measuring
masks, wafers and panels.

35   <u>Description of a preferred embodiment</u>
     The mask blanks are cut and polished by a glassmak-
ing company. The surface figure is controlled to a maxi-

16

mum error corresponding to a quality class of the glass
product. The glass plate is coated with a sputtered film
of chromium and a photoresist coating is spun on. In the
preferred embodiment of the invention the flatness of the
5   front and backside of the glass is measured before and
after the coating with chrome and after the resist coat-
ing. A flatness map is generated for each side together
with other auxiliary information such as the exact thick-
ness and the Young's modulus of the glass material. Each
10   glass plate has a serial number engraved at the perimeter
of the chrome surface before the chrome coating so that
the identity of the plate can be tracked through-out it's
lifetime. The serial number is engraved in the glass sur-
face or chrome film in clear text and machine-readable
15   format, e.g. by laser ablation. It is also possible to
laser engrave an identity mark inside the volume of the
glass or use other marking methods such as magnetic re-
cording in the chrome coating or embedding of a memory
devise in the glass plate. Identification of semiconduc-
20   tor wafers by an engraved marking is standard in the
semiconductor business, and in the invention the same
would be applied to mask blanks. Any other secure identi-
fication system can be used, for example storing and
shipping the mask blanks in marked and bar-code labelled
25   boxes.

        The mask blank maker stores the flatness data for
each blank on a computer and the data is published on a
network accessible to the mask makers at a later time,
e.g. on an Internet server. Alternatively the data could
30   follow the blank, e.g. on a diskette shipped with the
blank or on the embedded memory device.

        How to measure the flatness and other properties of
the mask blank is known in the art. Flatness is often
measured by interferometers made by for example the com-
35   panies Möller-Wedel, Zygo and Tropel. The resist thick-
ness can be measured with spectroscopic reflectometry,
ellipsometry and other optical methods. The chrome thick-

17

ness can be measured by optical transmission or inductive methods and the reflectivity of the chrome layer by reflectometry. The exact thickness can be measured with mechanical or optical methods.

5   When a mask or reticle is ordered by a semiconductor company the specification includes the serial number of the stepper for which the mask is written. The clamping system of each stepper is characterised by a file of geometrical data describing the method of clamping, but also

10   and most important the individual imperfections of the clamping system. This information is stored on a network accessible to the mask maker or sent to the mask maker together with the order. The mask maker can also pull information about the process, e.g. uniformity data for a

15   etching step from the semiconductor manufacturers computer. Alternatively the data can be attached to the order document as embedded data or as separate documents.

The mask maker who typically have several mask writers of different kind have a similar database of data for

20   his writing systems and processes. He also has empirical data of how the mask is distorted by the application of a pellicle, the stretched film that acts as a dust protection on the finished mask.

When the chrome and resist were applied at the mask

25   blank manufacturer the blank bent due to stress built into the films. When the resist is removed during processing in the mask shop the stress from the resist disappears and the blank goes back to the state it was before the resist was applied. More important is that when a

30   pattern is formed by partial removal of the chrome the stress from the chrome film is partially relieved. With knowledge of the bending caused by the application of the chrome film during manufacture and the pattern to be written it is possible to predict the deformation of the

35   plate by patterning of the chrome.

During the planning of the writing job the mask maker fetches the applicable information for the stepper

18

or exposure station in which the mask will be used, for
the maskwriting equipment, for the blank and for the
pattern. Using the error model a total combined error can
be computed and corrected for, optionally using the MEEF
5   factor or a similar function as a transfer function from
correction to result in the finished pattern. In another
application of the invention the collected information
can be used to select among mask blanks, writing systems
and processes. A simple example is the selection of
10 blanks for uniformity for patterns that occupy different
areas on the mask. Of course, the principle of the
invention is the same whether the end result ("the
output") is a chip, a display panel or just the mask.
     This contains geometrical information about the
15 clamping geometry, imperfections of the clamping struc-
ture and also other known image distorsion created by the
tool and subsequent processing.

The maskwriter

20   In a preferred embodiment the mask writer has sev-
eral provisions for correction of distortions caused by
the processes chain from patterning to use. First it has
a precision stage controlled by laser interferometers
with a adjustable scales in x and y, corresponding to
25 uniform shrinkage or expansion plus uniform bending
across each axis, such as may result from built-in film
stress. Secondly it has adjustments for orthogonality and
trapezoidal distorsion, by modification of the driving of
the servos servos and by software. For higher order er-
30 rors such as barrel distorsion, mirror bow and irregular-
ity of the coordinate system, the maskwriting machine has
an xy correction map that sends position-dependent off-
sets to the servo systems. The information collection and
error prediction system sends a uniform scale and an xy
35 map to the maskwriter for each mask to be written, said
map being the pattern correction necessary to correct for

all known errors. These of course include the mask-
writer's own stage errors.

Furthermore the maskwriter has a clamping structure
that is adapted to the particular type of mask blank to
be written. In one embodiment the plate is placed on
three supports so that the deformation of the plate in
the maskwriter is independent of the plate shape and can
be computed easily. For the most accurate correction the
supports are placed identically to similar supports in
the equipment using the mask, e.g. near two adjacent cor-
ners and at the center of the opposite side.

In many cases it is not possible to support the mask
plate at three points. Especially for larger-size masks
it is necessary to have more than three supports. In this
case it is impossible to hold a mask without introducing
bending moments, if not both the support structure and
the plate are perfectly flat. In one embodiment the
forces exerted on the supports from an ideal
plate/support structure combination are derived theoreti-
cally and the geometry of the supports is adjusted until
the force on each support matches the theoretical force.
In another embodiment the non-flatness of the plate is
known beforehand and the geometry of the clamping struc-
ture is modified so as to minimise bending forces. Other
deformations such as that from gravitational sag and sub-
sequent process distortion are computed and corrected
for.

In another embodiment the support structure is not
adjustable but geometrically characterised, so that it is
possible to compute the bending of a particular plate re-
sulting from the combination of plate non-flatness and
clamping geometry.

I another embodiment the maskwriting system itself
is adapted to measure parameters that are needed for the
correction, such as the flatness of the substrate. If the
flatness is measured after clamping in the maskwriter,
the measured data can be used in several ways. First it

20

can be used to check the model of the clamping structure.
Secondly it can replace the detailed knowledge of the
stage flatness, since the exact form and the clamping de-
formation can be calculated from the surface flatness
5   combined with flatness data of the substrate. In the case
that there is no flatness data available and the plate is
known to be flatter than the stage and/or the gravita-
tional sag, the measured deviation from flatness indi-
cates a real deformation and can be used for an approxi-
10   mate correction.

A measurement of other parameters such as resist
thickness can also be integrated with the maskwriter, to
provide information necessary for the correction inde-
pendent of the mask blank maker or to be used with in-
15   house spun plates.

The invention can be used in different types of
maskwriters using scanning laser beams, spatial light
modulators or particle beams.

20   *Exposure station*

Like the maskwriting equipment the exposure station
or stepper that is going to use the mask to print the
pattern on a workpiece has a number of errors, such as
image distorsion in the exposure step and warpage in the
25   subsequent processes. In a preferred embodiment the mask
is supported by three supports and the clamping gives no
additional bending forces beside the gravitational sag.
In another preferred embodiment other design constraints
makes it necessary to clamp it kinematically over-
30   restrained, i.e with more than three support points. The
pattern distorsion due to the bending forces resulting
from imperfect geometry can be cancelled by modification
of the clamping structure as in the maskwriter or by pre-
diction and precorrection of the mask.

35   The geometry and the errors of the exposure station
are characterised and stored as a machine parameter file,
which contains enough information to compute the errors

21

of a real physical mask and how it is printed. The file
may, apart from the identity and bookkeeping information,
contain, the number of supports, their xyz coordinates
and compliances and optional springloading, further
5   distorsions of the machine's coordninate system etc.

It is also valuable to have a process distorsion
file which contains an error map for how an exposed work-
piece is distorted by subsequent processing. An example
is a glass panel for a TFT-LCD display that may shrink by
10 several tens of ppm in high-temperature steps.

Metrology tools

The masks and the exposed workpieces are measured in
coordinate measuring system, such as those commercially
15 available from the companies Leica and Nikon. The metrol-
ogy tools also have a clamping geometry and built-in er-
rors that can be described in a machine geometry file.
Even though the metrology tool does not impose its errors
directly to the mask, it does so indirectly by being the
20 reference against which all other systems are calibrated.

Computing the bending forces

A mask blank has a simple geometry and is made from
high-quality quarts or glass. Therefore, it can be repre-
25 sented by a simple finite element model as is well known
to a person skilled in mechanical design. All errors are
small compared to the size of the plate and the resulting
errors can be computed by linear superposition of distor-
sions from different sources, e.g. gravitational sag and
30 bending due to clamping are additive. This allows for
simplified methods of analysing the elastic glass plate
by decomposition of different bending modes. This is ad-
vantageous for real-time correction on an embedded com-
puter in the mask-writer, but it is equally possible to
35 run a full finite element simulation on an embedded com-
puter with adequate memory and power, or at an offline
workstation.

22

Given a machine parameter file, with the geometry of
the supports and the orientation of the force of gravity
relative to the plate, and a plate parameter file with
the geometry, flatness and elastic properties of the
5   plate, the computer can use the finite element model to
find the shape of the plate, the distorsion of a pattern
on its surface, and the contact forces at the support
points.

If there are many support points it is not known be-
10   forehand that a particular non-flat plate really makes
contact to all supports. It is, however, possible to find
which points make contact. In principle the solution has
to be self-consistent. The plate makes contact to a sup-
port point if there is a positive contact force, includ-
15   ing the effect of possible spring-loading. By this method
it is also possible to find the approximate area of con-
tact between the mask blank and a flat surface, e.g. a
flat stage top, by representing the flat surface by an
array of contact points.

20   Because of the linearity of the elastic plate and
the simple geometry it is also possible to derive a sim-
plified set of simultaneous linear equations describing
the deformation of the workpiece due to forces at a num-
ber of predefined positions on the workpiece. Other posi-
25   tions can be treated by interpolation between the basic
computational points. The system of equation is solved
for the geometrical constraints given in the geometry
files and the bending forces are derived. These are added
to the gravitational sag that depends only on where the
30   support points are placed.

Correction of other mask blank related errors

Other properties of the mask blank affect the qual-
ity of the image, such as the resist thickness, the
35   chrome thickness and the reflectivity of the chrome.
These can be measured in the same way as the flatness or
in fact in the same equipment.

Implementation of the correction

Once the errors are predicted and the appropriate corrections are computed there are two principally dif-
5   ferent methods to apply them. Either the pattern data is modified, e.g. the corner points of each feature are moved, or else the corrections are fed to the writing hardware, such as position servos for placement and modulator or light source for intensity control. The former
10   method is more general and can in principle give arbitrary large corrections. It is also the only possible alternative for shape corrections involving serifs and similar features. For small and slowly varying corrections the second method gives a smoother correction,
15   since it has the resolution of the interferometer while modification of the data only has the resolution of the address grid. A second advantage is that the data can be prepared offline without knowledge of the mask blank and machine specifics and the corrections applied at the time
20   of writing. But for very dense patterns the data preparation has to be done in real time anyway, so there is little difference in logistics whether the correction is applied to the pattern or to the writing hardware. Correcting the pattern is perfectly flexible: corrections can be
25   applied for placement, size and shape and there is no limit to the size or complexity of the corrections.

Real-time pattern correction

With a real-time data path with high processing ca-
30   pacity it is possible and advantageous to apply corrections for beam size or resolution effects and stray exposure together with all other corrections at the time of writing. In a typical implementation there is a bank of parallel processors, possibly organised in groups doing
35   different steps of the data preparation, with up to several hundred CPUs and ASIC:s. The slowly varying corrections, e.g. for clamping distorsion, will not effect the

work load or data flow appreciably, but corrections for
resolution, beam size and stray effects generate immense
amounts of extra data and require processing capacity to
match the data flow. However, there is an big advantage
5 to real-time correction and for exactly this reason. The
data volumes are difficult to handle with off-line cor-
rection. In a commercial mask shop where a maskwriter is
running essentially 24 hours a day, there is also no cost
benefit of doing the correction off-line, since an
10 equally powerful computer is needed to furnish corrected
data to the maskwriter at full writing capacity.

The general concept of pattern correction to compen-
sate for the limited resolution is known in the prior
art. In the invention the correction is done in real time
15 as a part of the real-time processing. For real-time cor-
rection of resolution, beam size and stray effects the
algorithm is preferably running on the maskwriter's em-
bedded processor bank. The control system supplies only
the parameters for the interaction between the image for-
20 mation and the pattern, e.g. a series of superposed gaus-
sian profiles representing the point-spread function or
the beam of the writer and exposure system, or a system
of rules for the correction. A typical rule is to add a
0.16 m serif to all outer corners in the pattern.

25 Correction of the imaging properties of the mask-
writer is preferably done transparently, with parameters
that are fitted to that particular maskwriter and process
but otherwise not changing. Once the parameters are set
up the user will not need to care, or even know, about
30 the correction, but will only see a mask pattern with a
more accurate representation of the input data.

Pattern correction for the exposure station is pref-
erably done in collaboration between the mask shop and
the chip or panel manufacturer. The manufacturer prints
35 some test patterns that are designed for extraction of
the model parameters. Once the model parameters are set
the correction could be transparent and automatically ap-

plied to all designs. The information system of the in-
vention pulls the parameters together with clamping data
and image distorsion when the writing job is set up. Or
alternatively the manufacturer would explicitly provide
5   another set of correction parameters, or correct the data
directly using his own correction model. However, we be-
lieve that the design of image correction models, design
of test patterns and extraction software will be the mis-
sion of specialist consulting companies, and that the
10   manufacturer will use the system in the transparent mode.
The information system of the invention provides the
framework, which makes such transparent operation possi-
ble and convenient.

Figure 9 shows a typical implementation of an error
15   correction system suitable for the invention using both
pattern modification and writing hardware control. The
writing hardware 901 prints a pattern 902 on the mask
blank 903 using a low-level representation of the pattern
904, e.g. a bitmap or a decomposition into small area
20   elementary forms such as trapezoids. The low-level format
is created from a geometrical database with a high-level
input 905, containing a geometrical description of the
pattern, such as a list of filled polygons. Since the in-
put format can contain the geometrical features in any
25   order and they can have any shape they are pre-processed
into an intermediate format 906 after having been dis-
tributed 907 from the external file interface 913 on a
number of parallel processors 908. For each conversion
step the data volume expands and the necessary processing
30   power increases. Therefore the final processing needs
more parallel processing units 909 than the pre-
processing. The error correction system has a control
unit that predicts the errors from the collected error
data and computes an appropriate pre-compensation based
35   on its set of models and rules. The correction of small
slowly varying size and placement errors is sent 912 to
the writing hardware, especially to the dose control and

the position servos. Pattern corrections are sent in the
form the correction rules to the datapath interface 913
and run on the embedded computer banks 908 and 909. Even
the pattern corrections can take different forms and sev-
5   eral correction algorithms can be run at different con-
version steps. For example, correction for the beam size
effects in the mask generator is suitable to run at the
last stage of the conversion, while the larger serifs
needed to compensate for the imaging effects in the step-
10   per are added to the pattern during the pre-processing
step.

For efficiency it is suitable for the different
processors to work on separate areas of the pattern, but
to apply corrections for non-local imaging effect the
15   processor needs to know the pattern in an area around the
actual point it is working in. Therefore the pattern is
cut into partly overlapping computation fields. The re-
dundant information is only used for the correction and
discarded after use. For faster processing of non-local
20   information, e.g. for correction of stray exposure, a
temporary representation of the pattern at a lower reso-
lution is created and used to compute background expo-
sure. It is possible to use more than one low-resolution
representation at a single time to represent phenomena at
25   different length scales.

In one embodiment the two processing steps are com-
plemented with a third step that runs on a separate bank
of processors essentially dedicated to pattern correc-
tion.

30   In a preferred embodiment of the invention two cor-
rection maps are computed, one for position and one size.
The position map has the form of a table with x and y de-
viations given at a grid of points. For a given stage po-
sition the corresponding s and y correction is computed
35   by interpolation in the correction map and the result is
fed as an offset to the position servos. The same method

is used for finding the correction of CD errors by interpolation in the CD map.

In a different embodiment the correction maps are computed and made available to the datapath. During the

5   conversion from pattern database to hardware-driving signals both position and size is corrected. In the preferred embodiment, which has a stripe-organised writing strategy, it is done at the fracture step, just before the pattern is divided into strips. The vortex points of

10 the pattern elements are simply moved according to the interpolated correction maps. Most pattern elements have edges parallel to the axises, and would after the correction have slanted lines, but since the scale of the corrections is normally of the order of a part per million

15 or less, all but a few edges are still parallel to the axises after their coordinates have been truncated to the resolution of the data preparation software, e.g. 0.1 nm. Before writing they are further truncated to the address grid of the writer, e.g. 4 nm for semiconductor reticle

20 at a specific specification level. The written pattern will have the smooth curves of the correction map snapping to the address grid, but with an appropriately chosen address grid this will give a negligible contribution to the error statistics.

25

The information system

An information system is built to manage the lithography errors in the chain from mask blank maker to user of the final products. The hub in the information system

30 is the mask maker where during job planning all information is collected and used to predict errors and precompensate them.

A convenient way to organise the information when several parties are involved, e.g. mask blank makers,

35 mask shops and mask users, is to have each party maintain its own information and store it on its own computer system. The computers are accessible from the mask maker's

28

computer by remote access over phone line, ISDN, high-
speed link or the Internet. In the latter case it is im-
portant that the integrity of the information is vali-
dated, so that the user of information knows it is com-

5   plete, unaltered and issued by the correct sender. The
parties involved may also want to have it confidential.
All this can be assured in modern communication links by
appropriate use of passwords, encryption, check figures
and digital signatures.

10

Workflow

It is the responsibility of the mask shop to find
the necessary corrections that will make a particular re-
ticle print without systematic registration errors. The

15   customer, i.e. the mask user, provides one or more pat-
tern files and the order document requests any special
treatment, metrology etc. In a preferred embodiment of
the invention the order document specifies the exposure
station where the mask will be used and optionally also a

20   process error description. During job planning and set-up
the mask maker's computer accesses the data from the mask
user, data which specifies the geometry of the exposure
station, including known imperfections, and image distor-
sions. Optionally the machine file also includes a map of

25   size errors created by the exposure step. If a process
file has been specified in the order document, it speci-
fies warping of the workpiece during subsequent process-
ing and optionally also size errors created by the proc-
ess. For example a plasma etching step is sensitive to

30   the "loading", i.e. the local density of pattern area ex-
posed to the plasma, and etches differently along the
edges of a chip. Since this is a systematic behaviour
that is repeated more or less in every design it can be
partly corrected for in the mask using information about

35   said mask.

When the writing job is planned a mask blank is as-
signed to the mask. The computer accesses the data stor-

29

age at the mask blank maker or a local storage with in-
formation files for the blanks that are in stock. The in-
formation file fetched corresponds to the particular mask
blank that will be used for writing the mask, and holds
5   information about the exact size and thickness as well as
relevant physical material properties. It also contains
flatness data, resist thickness, chrome thickness and re-
flectivity and data relating to the bending force created
by built-in stress in the chrome and resist. The scheme
10   is, of course, independent of the exact materials used,
and other types of existing or future mask blanks can be
handled in a similar fashion.

Data file formats

15   The data file formats are designed to be extendable
by having the data fields tagged with keywords. A new
feature can be included after definition of a new keyword
and old data files will still be compatible. For simplic-
ity the data files in the preferred embodiment are ASCII
20   character files. This allows for simple debugging and
files can be modified or created in any text editor or
spread-sheet program. To avoid the risk of inadvertent
change of a file it is locked by a checksum and validated
by a digital signature. For machine-generated files these
25   are generated automatically, but hand edited files need
to get the checksum and signature added by a special
validation program. This gives a reasonable trade-off be-
tween security and flexible engineering and debugging.
For encryption any commercial encryption program can be
30   used.

Example of a system using an embodiment of the in-ventive method

     A system for producing large-area displays with dis-
tortion control according to an embodiment of the inven-
35   tion should now be described more thoroughly.
     Referring to fig 10, an embodiment of the system for
producing large area display panels according to the in-

30

vention is shown. The system could be used for producing shadow masks for conventional CRT (Cathode Ray Tube) displays, but is especially useful for producing TFT (Thin Film Transistor), CF (Color Filter), PDP (Plasma Display

5 Panel) or PALC (Plasma-addressed liquid crystal) displays.

The system comprises a first mask producing means 1001 for producing a mask with a predetermined pattern according to input data. The mask producing means is

10 preferably a microlithographic writing device for writing with high precision on photosensitive substrates. The term writing should be understood in a broad sense, meaning exposure of photoresist and photographic emulsion, but also the action of light on other light sensitive me-

15 dia such as dry-process paper, by ablation or chemical processes activated by light or heat. Light is not limited to mean visible light, but a wide range of wavelengths from infrared to extreme UV. Such a mask producing apparatus is previously known from e.g. EP 0 467 076

20 by the same applicant. In general the apparatus comprises a light source, such as a laser, a first lens to contract the light beams, a modulator to produce the desired pattern to be written, the modulator being controlled according to input data, a reflecting mirror to direct the

25 beams towards the substrate, and a lens to contract the beams before it reaches the substrate. The mirror is used for the scanning operation to sweep the beam along scan lines on the substrate. Instead of a mirror, other scanning means may be used, such as a rotating polygon, ro-

30 tating prism, rotating hologram, an acousto-optic deflector, an electro-optic deflector, a galvanometer or any similar device. It is also possible to use raster scanning or spatial light modulators. Further, the substrate is preferably arranged on an object table which has a mo-

35 tion in two orthogonal directions relative to the optical writing system, by means of two electrical servo motors.

31

The system according to the invention further comprises microlithographic exposing means 1002 for exposing a photosensitive panel substrate with light and with use of the mask to impose the pattern of the mask on the sub-
5   strate, whereby said substrate has a layer being sensitive to said light. Several such exposing means are also previously known in the art. The exposing means could be of the contact copy type, proximity exposure type, or a projection aligner. The system according to the invention
10   could also be used in a direct writer, whereby the compensation is not made in a physical mask, but in a data mapping controlling the writing beam. For TFT and CF display panels projection aligners are usually used, and for PDP and PALC the contact or proximity type are frequently
15   used.

Furthermore, the system comprises measuring means 1003 for measuring the pattern on the substrate and detecting deviations relative to the intended pattern as given by the input data. This could be done by measuring
20   the geometrical position of the pattern, preferably at some reference positions, to get a so called registration mapping, and compare it with the intended pattern which is deducible from the input data. Further, the width of lines in the pattern, the so called CD (Critical dimen-
25   sion), could be measured. Measuring equipment is commercially available, and for example the equipment could comprise a CCD-camera or be based on interferometry.

From the measuring means 1003 a distortion control signal is sent to a second mask producing means 1004.
30   This second mask producing means could be a separate apparatus, but is preferably the same as the first mask producing means 1001. This second mask producing means is fed with input data describing the intended mask pattern to be written, and is also fed with the distortion con-
35   trol signal from the measuring means 1003, whereby the writing process for producing the second mask is controlled to modify the pattern to compensate for the meas-

32

ured deviations, and thus compensate for production dis-
tortions. The measurement is preferably made after the
subsequent processing steps of the panel as well, i.e.
the development, blasting and/or etching, whereby system-
5   atic errors from theses processes are taken care of in
the compensation as well.

The compensation in the mask writer could be accom-
plished in different ways. In a writer of the type de-
scribed above, with an object table continuously moving
10   in a slow strip direction and a scanner sweeping in a
fast scanning direction, the compensation could be made
according to a surface mapping. According to this mapping
the compensation in the scanning direction could be ac-
complished by e.g. offsetting the starting time of the
15   beam during the scanning. In the stripe direction the
compensation could also be made by time offsets, either
directly or indirectly by means of different ramp func-
tions. There are also other possible way to accomplish
such compensation. For example the compensation could be
20   made by controlling the servo motors for the object ta-
ble, by adjustment of the time dependent angle of the
scanners, by changing the input data or by controlling an
internal control unit such as piezoelectrically con-
trolled mirrors.

25   However, if a direct writer is used, the same type
of compensation could be made in real time.

Compensation for deviations in the line width, CD,
could be accomplished in the same way as deviations in
the registration. However, this compensation could also
30   be made by changes in the power of the writing beam, i.e.
the exposing dose, by changing the laser output or having
an analog modulator. This compensation could be accom-
plished by means of a herefore adapted dose mapping to
control the dose.

35   When the second mask is used in the same exposing
means 1002 all systematic errors depending on different
temperature conditions, errors in the exposing means

etc., are compensated for, and the pattern precision of the produced display panels are greatly improved.

The first mask could either contain the same pattern as the intended pattern for the second mask, i.e. the
5   pattern not being compensated, or contain a reference pattern, intended for deviation measure only.

Further, error data could be accumulated, and a rolling means value could be used for the compensation. The error compensation could also be a combination of
10 several different part error compensations. Those part compensations could be based on the premises for the process, e.g. which stepper and type of glass that is being used. Hereby the total error compensation could be a combination of one or several error compensations for each
15 process step.

Above, a system for passive distortion control has been described. In this system compensation is made for the processes and equipment being used in the system. However, the compensation is not adapted for different
20 panel substrates. In this passive system a measurement to alter the distortion compensation is preferably made once for every new batch of substrates, and thereafter the same mask is used for producing all the panels in the batch. This passive distortion control is specifically
25 useful for production of TFT or CF displays. The requested precision for the patterns on the mask for this production is extremely high, and the masks are very difficult, and thereby expensive, to manufacture. On the other hand the masks last for a long time in this produc-
30 tion.

The system according to the invention could also comprise second measuring means 1004 for measuring the thickness of the light sensitive layer on the substrate prior to the exposure, whereby said measurement is also
35 used for said compensation. Hereby the compensation is adapted for varying resist layers between different batches of substrates. Such batch wise compensation could

34

also be accomplished with use of data specified by the
manufacturer.

This second measuring means 1004 could also be used
for measuring each and every panel substrate that is go-
5   ing to be exposed, and thereafter adapt the process for
each individual panel. Hereby the system could compensate
for varying glass quality in different panels, varying
thickness and quality of the resist or emulsion of the
substrate area, different form variations etc. This ac-
10   tive distortion control is especially useful for produc-
tion of PDP or PALC display panels, where the masks are
comparably easy and inexpensive to produce. This method
could also be used for direct writers.

In the active distortion control the panel is ini-
15   tially measured, regarding e.g. resist thickness. Many
such measuring methods are available for someone skilled
in the art, e.g. a test exposure, dosimetry, of the sub-
strate with different doses, by profilometry, interfe-
rometry, confocal microscopy, by an interferometric
20   method or the like. The shape of the substrate could also
be initially measured, and this could be accomplished by
known methods such as moiré interferometry, projected
fringes, laser triangulation, ordinary interferometry
etc. Preferably already existing patterns are also ini-
25   tially measured, whereas such exists. Display panels are
usually exposed in several separate steps, typically 3-7
exposing steps, and normally the same exposing station is
used for all the exposures. By writing masks with compen-
sation for individual errors in different station the
30   display producer could schedule the production more
freely, independent of which stations that is used. This
is of great importance for making the production more ef-
ficient and the utilisation of the stations better.

Referring now to fig 11, a method for producing
35   large area display panels according to the invention, and
with use of the above-mentioned system will be described.

35

The method according to the invention comprises a
first step S1 in which a mask with a predetermined pat-
tern according to input data is produced. Thereafter the
mask is used for microlithographically exposing a photo-
5 sensitive substrate with light to impose the pattern of
the mask on the substrate, whereby said substrate has a
layer being sensitive to said light, in step S2. The ex-
posed pattern is then measured, possibly after several
subsequent processing steps, or even in the finished
10 product, in S3, to detect deviations of the exposed pat-
tern relative to the intended pattern as given by the in-
put data. In step S4 a distortion control mapping is then
produced, to be used in step S5 during production of a
second mask having a pattern according to input data and
15 modified to diminish the measured deviations, and thus to
compensate for production distortions. In the last step
S6 the second modified mask is then used in a photolitho-
graphic fabrication of display panels. Similar compensa-
tion may be used in a direct writer, where the compensa-
20 tion could be made in a data mapping.

The invention shall not be limited to the embodi-
ments described above, which are only examples of imple-
mentation. For example what is said above about chrome-
on-glass masks is equally applicable to masks made from
25 other materials, e.g. with coatings of other metals, iron
oxide, diamond-like carbon, multilayer coatings etc. ,
and with other substrate materials such as calcium fluo-
ride, Zerodur, silicon etc, as well as for both transmis-
sive and reflecting masks and masks which work by scat-
30 tering. It is also applicable to stencil masks and mem-
brane masks for particle-beam and x-ray lithography.

36

CLAIMS

1. A method for predicting and correcting geometrical errors in lithography using masks, such as large-area photomasks or reticles, and exposure stations, such as wafer steppers or projection aligners, printing the pattern of said masks on a workpiece, such as a display panel or a semiconductor wafer, comprising the steps of
- providing a mask substrate,
- providing a pattern data file,
- providing a mask writer for writing said pattern onto said mask substrate,
- collecting information about at least one of the following:
    - information about the mask substrate
    - information about the mask writer
    - information about the exposure station, and
    - information about behaviour of a processing step
    that will occur after the writing of the mask;
- predicting from said information distorsions that will occur in the pattern, when it is subsequently printed on the workpiece
- calculating from said prediction a correction map to diminish said predicted distorsion, and
- exposing said pattern onto said mask substrate while applying said correction map for said distorsions.

2. A method according to claim 1, wherein the information being collected is information about the geometry and elastic properties of the mask substrate.

3. A method according to claim 2, wherein the collected geometry information comprises information relating to the flatness of the mask substrate.

4. A method according to any one of the preceding claims, wherein the collected information comprises information relating to the properties of the resist on the mask substrate.

5. A method according to claim 4, wherein the infor-

RECTIFIED SHEET (RULE 91)

mation relating to the properties of the resist on the
mask substrate comprises information relating to resist
thickness, resist softbake variations and built-in stress
in the resist.

5   6. A method according to any one of the preceding
claims, wherein the collected information comprises in-
formation relating to the properties of chrome coating on
the mask substrate.

      7. A method according to any one of the preceding
10   claims, wherein the method further comprises providing a
mathematical model of the mask substrate, e.g. a finite
element model, whereby the prediction of the distorsions
occuring in the pattern as well as the calculation of the
correction is done by means of the mathematical model.

15   8. A method according to any one of the preceding
claims, wherein said mask substrate further is associated
with an identification code, and the physical properties
of said mask substrate is measured and stored as a data
file, whereby the step of predicting the distorsions oc-
20   curing in the pattern comprises reading of said identifi-
cation code for said selected mask substrate and fetching
the corresponding data file and predicting by means of a
model describing the behavior of the mask substrate and
by means of said data file the distorsions occuring in
25   the pattern printed on the workpiece.

      9. A method according to any one of the preceding
claims, wherein said mask writer and/or said exposure
station comprises a clamping structure for holding of
said mask substrate and whereby the mathematical model
30   used in the prediction step combines said flatness infor-
mation with the geometrical properties of the clamping
structure of said piece of equipment.

      10. A method according to claim 9, where at least
two lithographic machines interacts with the pattern on
35   the workpiece, e.g. a mask generator and a projection
printer using masks from the mask generator, each with a
clamping structure for holding the workpiece, said ma-

RECTIFIED SHEET (RULE 91)

38

chines having different clamping structures and at least
one of the machines having a kinematically over-
determined clamping structure, comprising the additional
steps:

5   - providing a numerical computer model describing the ge-
ometry of the workpiece,
- further characterizing at least one machine having a
kinematically over-determined clamping structure and pro-
viding data for the clamping structure,

10   - using the model of the workpiece and the data for the
clamping structure to compute the distorsion of the pat-
tern due to different clamping in lithographic machines.

11. A method according to claim 9, where the pre-
dicted clamping distorsion is merged with other predicted

15   distorsions, e.g. distorsion due to exposure tool imper-
fection and shrinkage distorsion due to high-temperature
baking of the workpiece, and the predicted sum of the
distorsions is corrected for.

12. A method according to any one of the preceding

20   claims, where the coordinate system of the mask writer is
modified to produce an essentially error-free coordinate
system at a later time, e.g. at a flat panel produced by
printing from the photomask.

13. A method according to any one of the claims

25   above, whereby the step of collecting geometrical infor-
mation comprises the sub-steps of
- measuring a result of the process , and
- filtering said measurement result,
whereby the prediction is a comparison between said fil-

30   tered result and the intended result, generating an error
map, and the correction is made by applying the inverse
of said error map to the input of said process.

14. A method according to any one of the preceding
claims, wherein said correction map comprises pattern

35   element size corrections for correction of the data pro-
vided from the pattern data file, for correction of said
distorsion.

39

15. A method according to any one of the preceding claims, wherein said correction map comprises pattern element position corrections for correction of the data provided from the pattern data file, for correction of
5   said distorsion.

16. A method according to claim 14 or 15, wherein the calculation of the corrections of the data provided from the pattern data file according to the correction map is made in at least two parallel processing means.

10   17. A method according to any one of the preceding claims, wherein said correction map comprises pattern element position corrections for correction of the position control for a servo system used to position the pattern on the substrate.

15   18. A method according to any one of the preceding claims, wherein said correction map comprises pattern element size corrections for correction of the dose provided during the exposure.

19. A method according to claim 18, wherein the cor-
20   rection of the dose is made by means of a dose modulator.

20. A method according to any one of the claims above, whereby the step of collecting geometrical information comprises the sub-steps of

- collecting a first set of information about at least
25   one of the following
    - the geometry of a mask writer
    - the geometry of an exposure station;
- collecting a second set of information about at least one of the following
30   - the layout of the pattern
    - measured flatness of the mask substrate;
and wherein a mathematical model for the interaction of the first and second set of information is provided, and the prediction of pattern errors is made by means of the
35   mathematical model operating on said first and second set of information.

40

21. A pattern correction system for predicting and
correcting geometrical errors in lithography using masks,
such as large-area photomasks or reticles, and exposure
stations, such as wafer steppers or projection aligners,
5 printing the pattern of said masks on a workpiece, such
as a display panel or a semiconductor wafer, comprising
- communication and storage means for retrieving and
storing geometrical information about at least one of the
following:
10   - a mask substrate
   - a mask writer
   - an exposure station,
   - a material processing step; and
- a computing unit for predicting an error map arising
15 from the combined geometrical information using a mathe-
matical model.
   22. A control system for predicting and correcting
geometrical errors in lithography using masks, such as
large-area photomasks or reticles, and exposure stations,
20 such as wafer steppers or projection aligners, printing
the pattern of said masks on a workpiece, such as a dis-
play panel or a semiconductor wafer, comprising:
- first computing means, and
- second computing means being connected to information-
25 gathering means for gathering information about at least
one of the following
   - a mask substrate
   - a mask writer
   - an exposure station,
30   - a material processing step;
where said second computing means comprises a storage
means for storing said information,
- means for transferring said information from said sec-
ond computing means to said first computing means,
35 where said first computing means comprises a mathematical
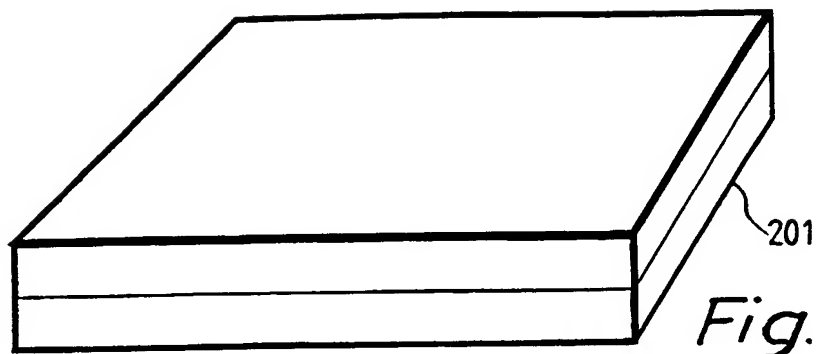error prediction model to generate an error correction

map using said information, the correction being intended
for controlling the mask making process.
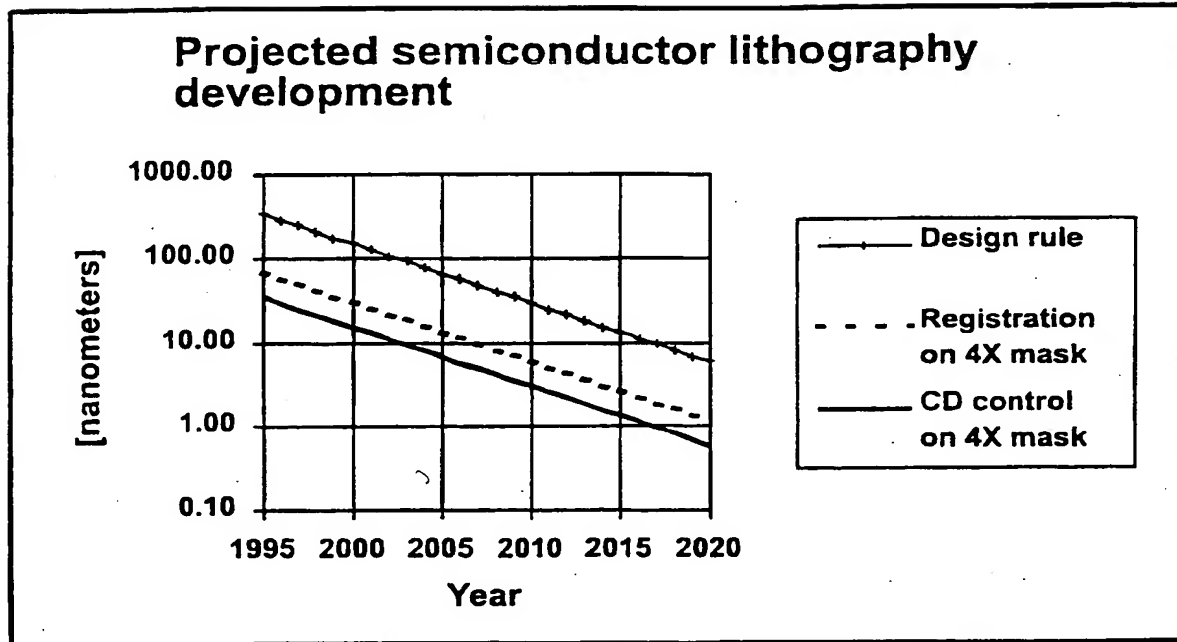
Fig. 1

Fig. 2a
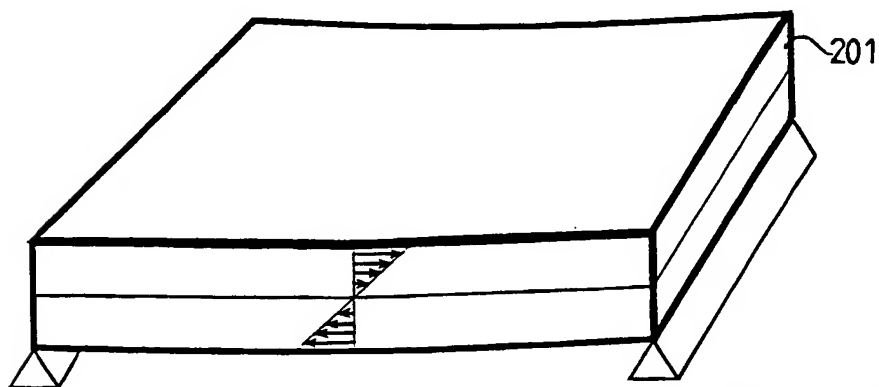
Fig. 2b
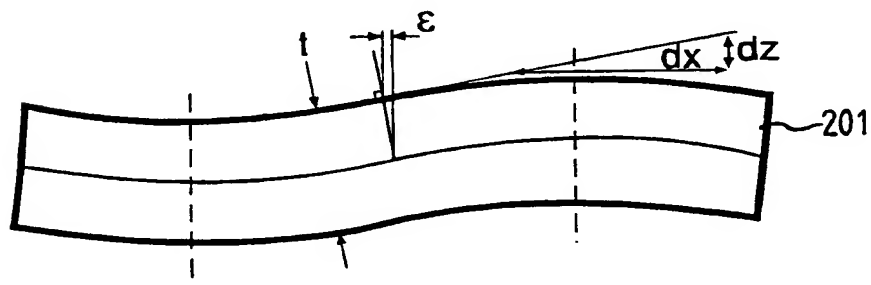
Fig. 2c
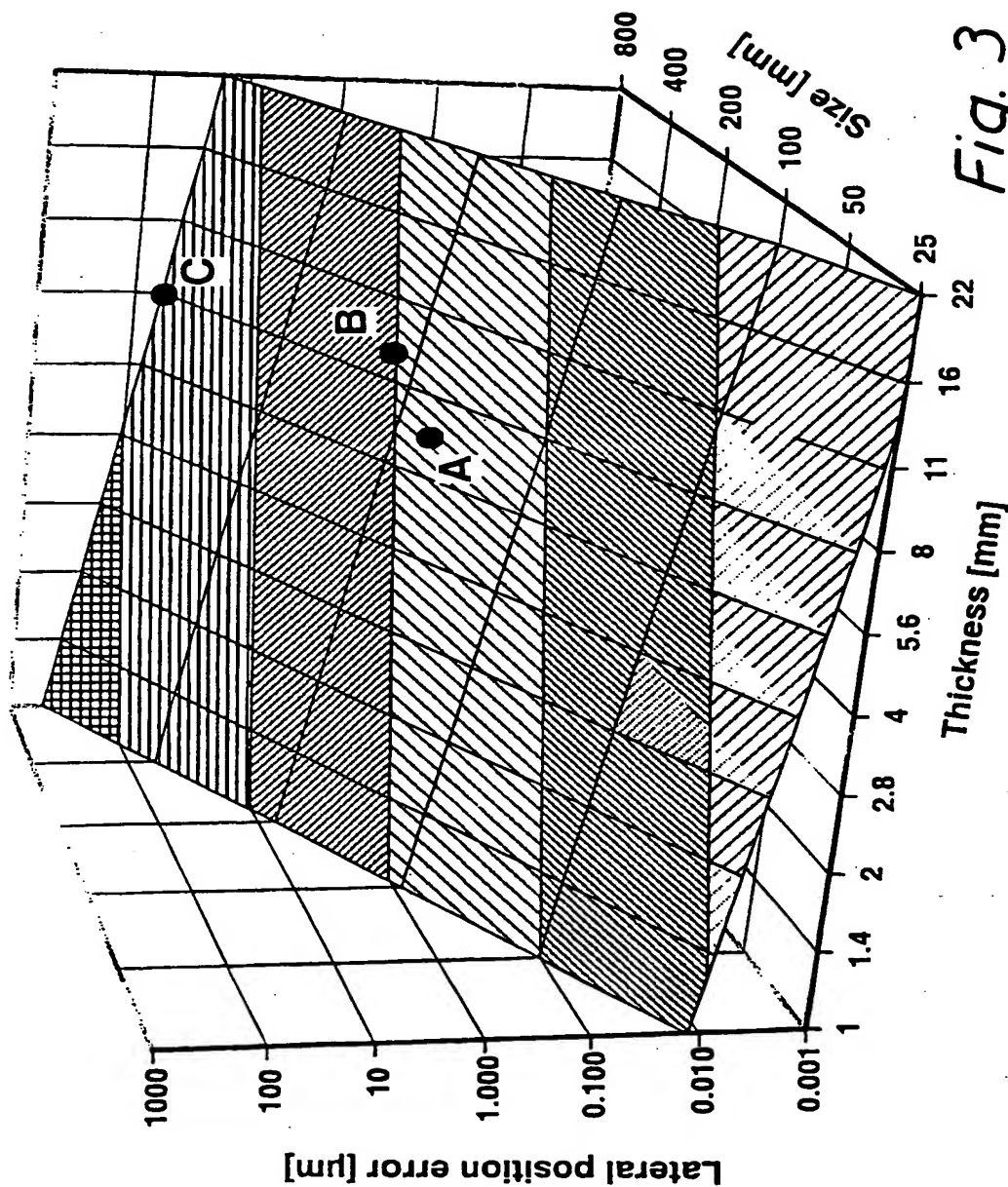
Fig. 3
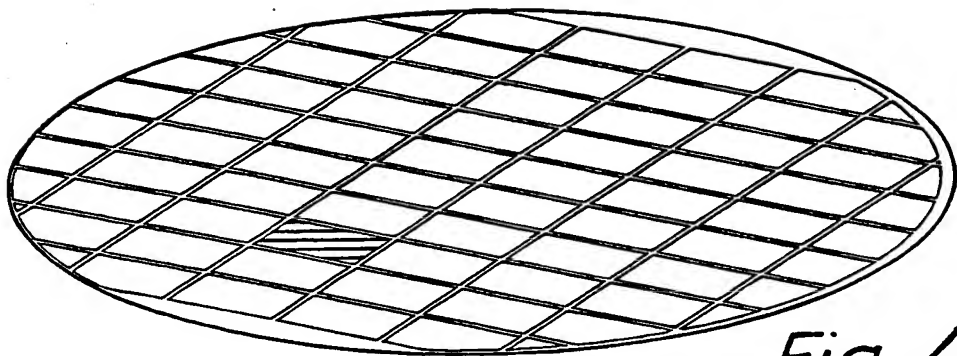
Fig. 4a
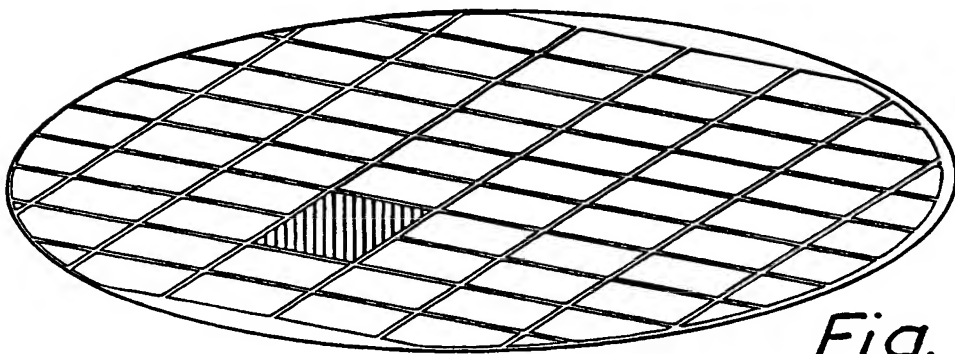
Fig. 4b
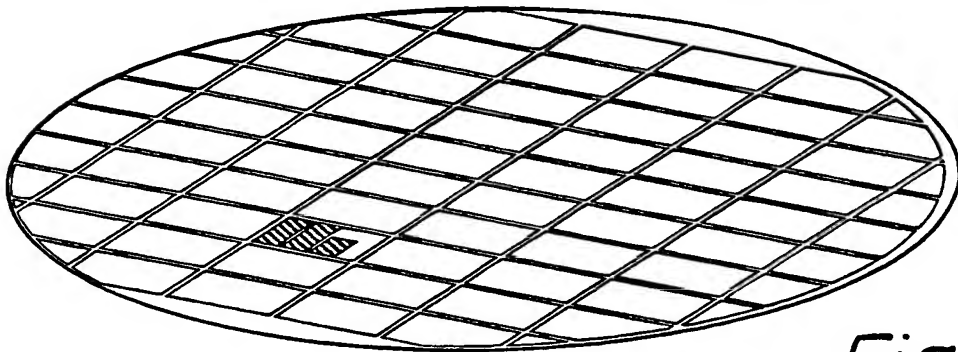
Fig. 4c
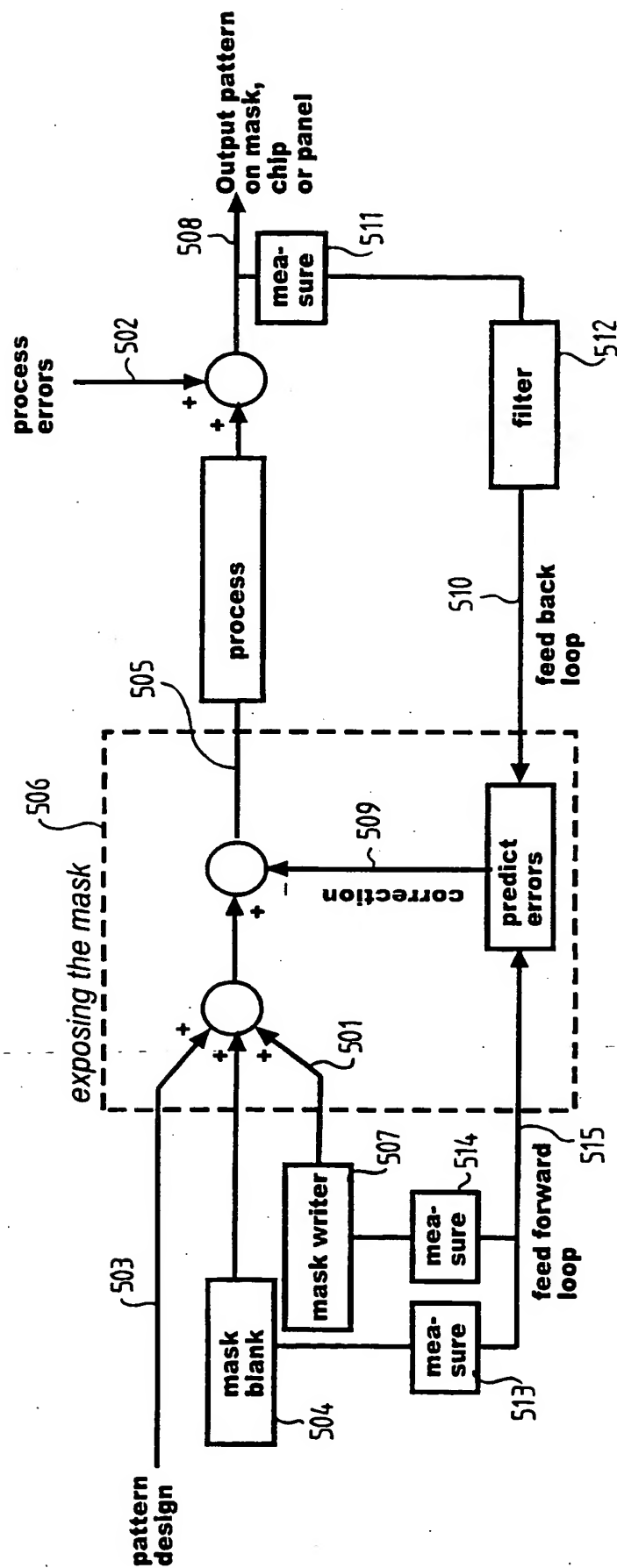
Fig. 5
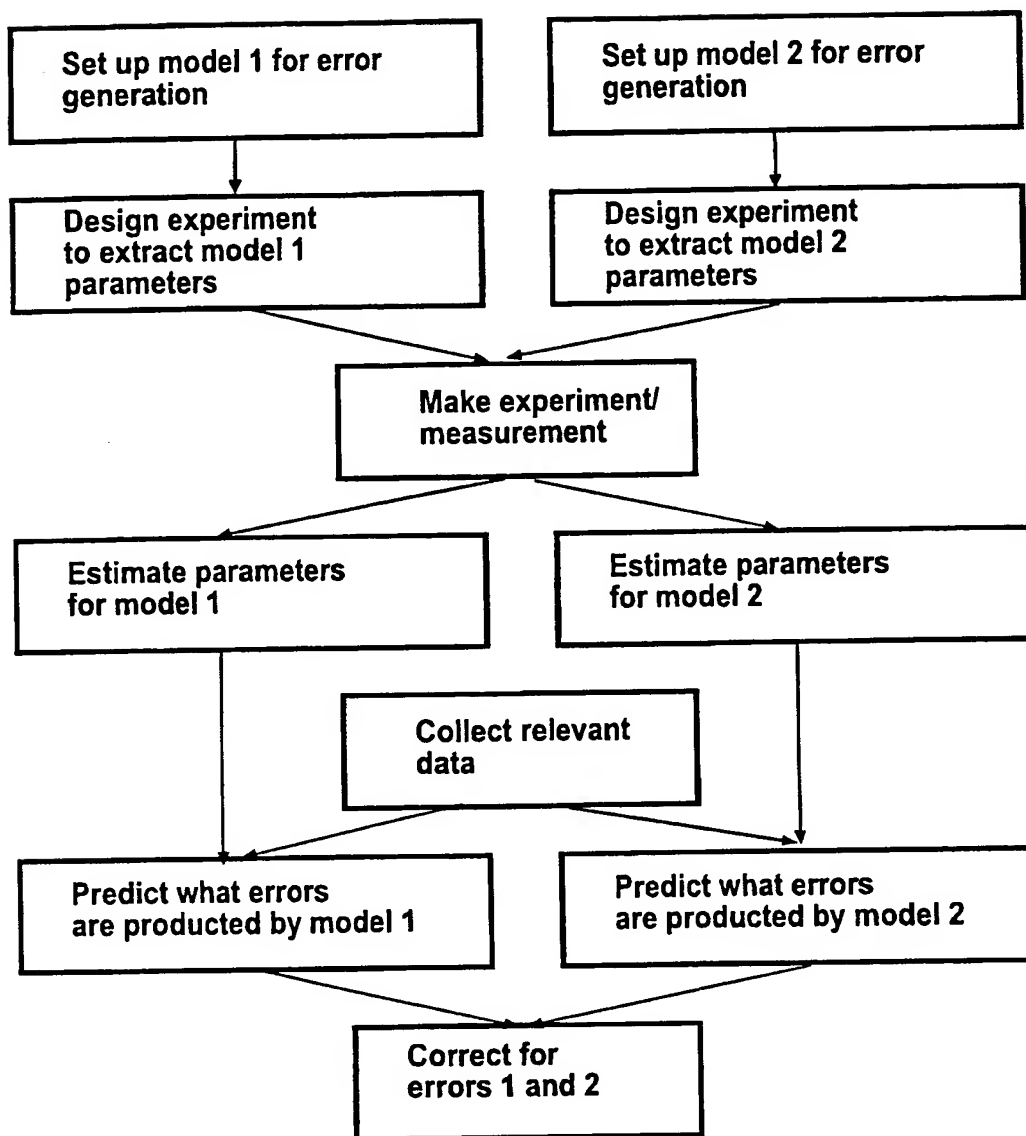
Fig. 6
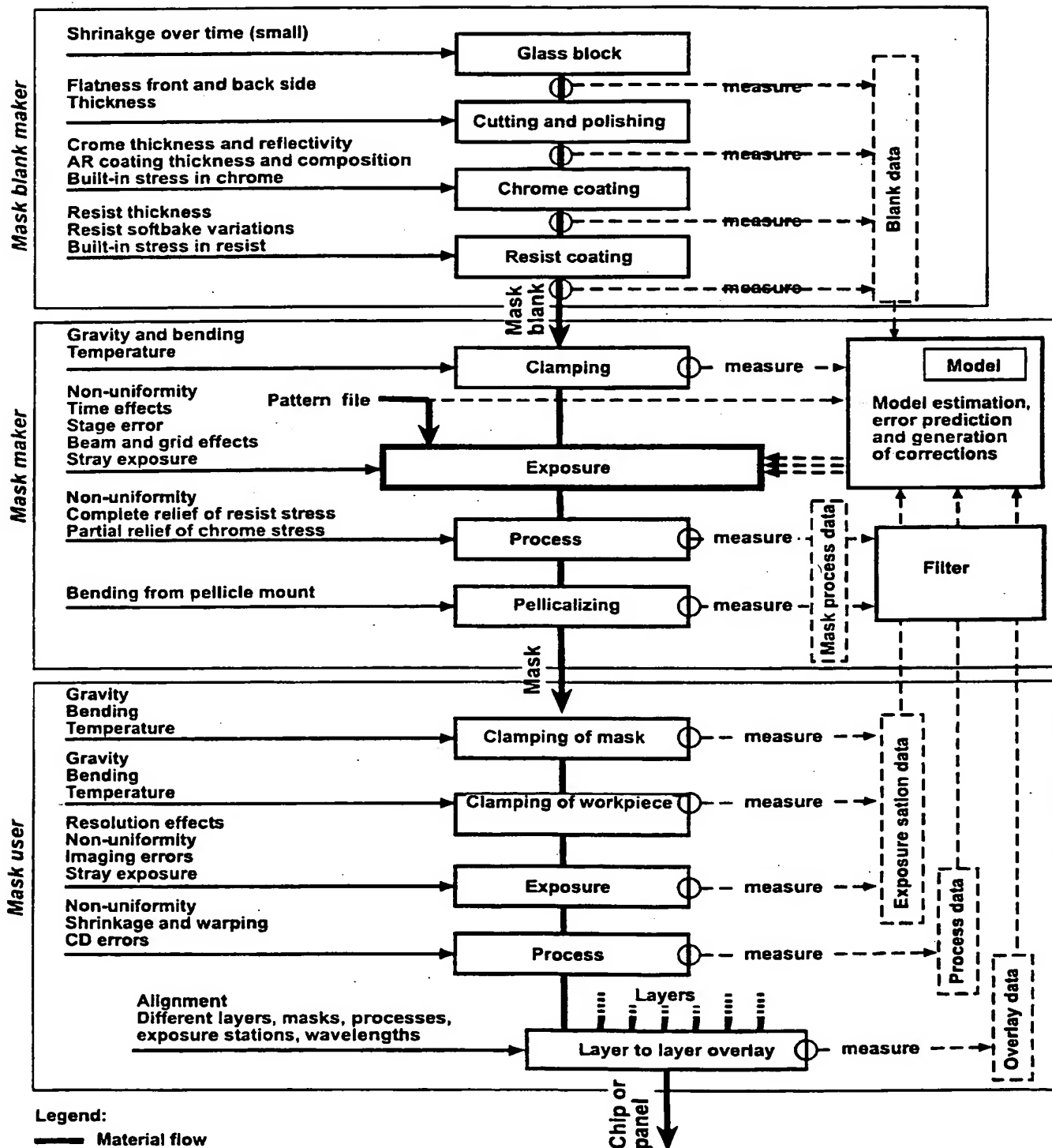
Fig. 7
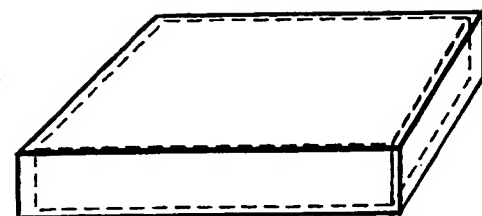
Isotropic Expansion:
Temperature, aging

Built-in shape:
follows the plate

Gravitational sag:
follows the type of
clamping

Clamping errors:
Follows particualr
piece of equipment

Shape-clamping
interaction:
non-linear cross
term

Coordinate errors:
Follows particular
piece of equipment

Fig. 8

Fig. 9

Measuring means → Mask producing means → Exposing means → Panel out

Panel in

1004

Data in

DC

1001

1002

Measuring means

1003

Fig 10

S1 — Production of first mask ⇢

S2 — Exposure ⇢

S3 — Measure

S4 — Distortion control

S5 — Production of second mask ⇢

S6 — Exposure ⇢

Fig 11

SUBSTITUTE SHEET (RULE 26)

Fig. 12

THIS PAGE LEFT BLANK

(51) International Patent Classification[7]: G03F 7/20, H01J 9/20

(21) International Application Number: PCT/SE00/01030

(22) International Filing Date: 22 May 2000 (22.05.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9901866-5   20 May 1999 (20.05.1999)   SE

(71) Applicant (for all designated States except US): MICRONIC LASER SYSTEMS AB [SE/SE]; Box 3141, S-183 93 Täby (SE).

(72) Inventors; and
(75) Inventors/Applicants (for US only): SANDSTRÖM, Torbjörn [SE/SE]; Banvägen 56, S-435 43 Pixbo (SE). EKBERG, Peter [SE/SE]; Norsbacken 5, S-181 31 Lidingö (SE). ASKEBJER, Per [SE/SE]; Lavvägen 3, S-184 70 Åkersberga (SE). EKBERG, Mats [SE/SE]; Brunnbjörnsvägen 56, S-722 42 Västerås (SE). THUREN, Anders [SE/SE]; Eskadervägen 48, S-183 58 Täby (SE).

(74) Agent: AWAPATENT AB; Box 11394, S-404 28 Göteborg (SE).

(81) Designated States (national): AE, AG, AL, AM, AT, AT (utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EE, EE (utility model), ES, FI, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KR (utility model), KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— With international search report.

(88) Date of publication of the international search report:
1 February 2001

[Continued on next page]

(54) Title: A METHOD FOR ERROR REDUCTION IN LITHOGRAPHY

(57) Abstract: The present invention relates to a method and a system for predicting and correcting geometrical errors in lithography using masks, such as large-area photomasks or reticles, and exposure stations, such as wafer steppers or projection aligners, printing the pattern of said masks on a workpiece, such as a display panel or a semi-conductor wafer. The method according to the invention comprises the steps of collecting information about a mask substrate, a mask writer, an exposure station, and/or about behaviour of a processing step that will occur after the writing of the mask. Further the method comprises predicting from the combined information distorsions occuring in the pattern, when it is subsequently printed on the workpiece; calculating from said prediction a correction to diminish said predicted distorsion, and exposing said pattern onto said mask substrate while applying said correction for said distorsions.
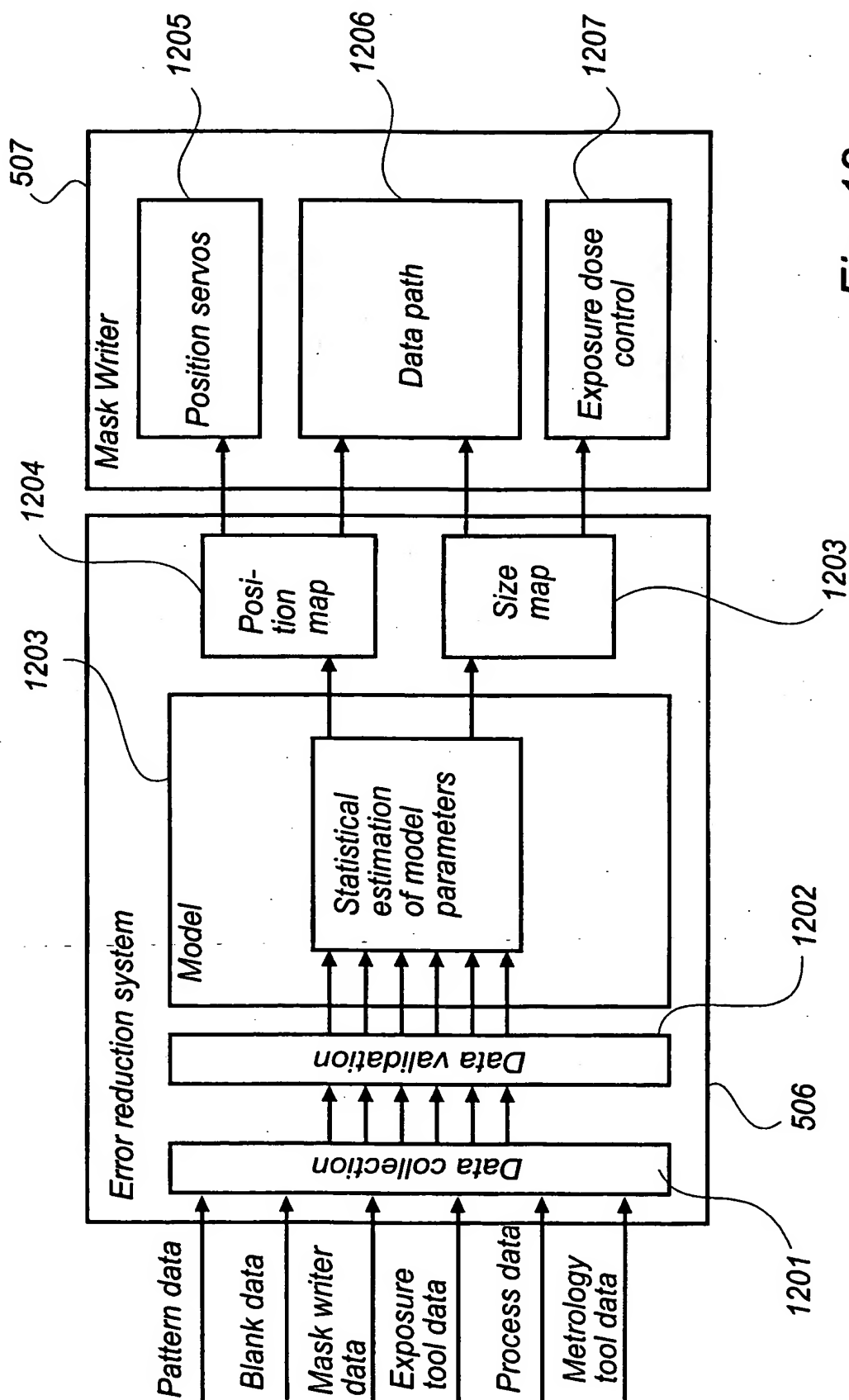
For two-letter codes and other abbreviations, refer to the "Guid-ance Notes on Codes and Abbreviations" appearing at the begin-ning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01030

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G03F 7/20, H01J 9/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G03F, H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5815685 A (KAZUYA KAMON), 29 Sept 1998 (29.09.98), column 1, line 15 - line 48; column 4, line 11 - column 5, line 51; column 11, line 34 - line 56	1, 11'-14'.18'-20'
Y		7,10'
A		2-6,8-10,9', 15'-17'
	--	
Y	EP 0307726 A2 (MOTOROLA INC.), 22 March 1989 (22.03.89), column 3, line 10 - line 42; column 7, line 12 - line 49	7,10'
A		1-6,8-9,9', 11'-20'
	--	

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 November 2000	1 5 -11- 2000
Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM	Tomas Erlandsson/MN
Facsimile No. + 46 8 666 02 86	Telephone No. + 46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1998)

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5593800 A (HIDEHIKO FUJIOKA ET AL), 14 January 1997 (14.01.97), column 15, line 62 - column 16, line 24; column 16, line 52 - column 17, line 17	2-3,9-10, 10',15'
	--	
A	US 5691115 A (YOSHIHIKO OKAMOTO ET AL), 25 November 1997 (25.11.97), abstract	2-3,9-10, 10',15'
	--	
A	WO 9705526 A1 (LSI LOGIC CORPORATION), 13 February 1997 (13.02.97), abstract	1-10.9'-20'
	--	
A	US 5879844 A (KAZUKO YAMAMOTO ET AL), 9 March 1999 (09.03.99), abstract	1-10,9'-20'
	--	

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE00/01030

Box I	Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II	Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see next page

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest   ☒ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (1)) (July 1998)

The claimed invention relates to prediction and correction of geometrical errors in lithography, in particular for manufacturing semiconductor devices.

In US 5815685 A an apparatus for predicting and correcting errors, which may occur in semiconductor manufacturing is disclosed. According to the disclosed document, errors occur due to a number of production steps (column 1, lines 15-49). Design data is input via an input unit (1) and the data is at first processed in a data compression unit (2) and then the data is used in an optical image calculation unit (3). That unit calculates the image that will be projected onto a wafer in a pattern transfer process. The output of the optical image calculation unit (3) is connected to a pattern prediction unit (4), which predicts the pattern which is going to be formed in a resist as a result of the pattern transfer process. The pattern calculated by the two units (3, 4) is compared with the designed pattern and a correction is made. The procedure is repeated until the calculated pattern is satisfactory and the mask is produced (figs. 2-3, column 4, line 11-column 5, line 52). It is not clearly stated how information is introduced into the calculating units (3, 4), but it must be considered obvious to realise that the disclosed apparatus must be provided with means for introducing and storing information, or else the calculating units (3, 4) would not be able to perform any meaningful tasks at all. For this reason, the invention according to claim 1 is not considered to involve an inventive step.

The numbering of the claims is confusing, since numbers 9-10 are used for two different sets of claims. In the text below claim numbers 1-8 and 9-10 (set 1) are based on pages 36-37 as amended under rule 91 (2000-06-20). These claims are referred to as claims 1-10. Claims 9-10 (set 2) and claims 11-20 are based on pages 38-41 as filed with the request (2000-05-22). These claims are referred to as claims 9'-20'.

<u>Invention I</u> (claims 2, 3, 18') relates the geometry and elastic properties of a mask substrate.

<u>Invention II</u> (claims 4-5) relates to the properties of the resist on the mask substrate.

<u>Invention III</u> (claim 6) relates to properties of the chrome coating on the mask substrate.

<u>Invention IV</u> (claim 7) relates to a mathematical model.

Invention V (claim 8) relates to an identification code and a data file associated with the identification code.

Invention VI (claims 9-10 and claim 9') relates to a clamping structure and its effects on a substrate.

Invention VII (claim 10') relates to modifications of the co-ordinate system of the mask-writer.

Invention VIII (claim 11') relates to measuring the results of a process and filtering the results.

Invention IX (claims 12'-17') relates to a correction map.

The only common special technical feature of inventions I-IX is a method according to claim 1. Since this feature does not avoid prior art, inventions I-IX, a posteriori, do not satisfy the requirement of unity of invention.

0072090A3_L>

US	5815685	A	29/09/98	DE	19534132	A	11/04/96
				JP	8297692	A	12/11/96
				KR	156792	B	16/11/98
EP	0307726	A2	22/03/89	DE	3854755	D,T	23/05/96
				JP	1074547	A	20/03/89
				KR	9614051	B	11/10/96
US	5593800	A	14/01/97	JP	7201725	A	04/08/95
				JP	7302743	A	14/11/95
				JP	8069958	A	12/03/96
US	5691115	A	25/11/97	JP	8306621	A	22/11/96
				US	5902705	A	11/05/99
				US	5932395	A	03/08/99
				US	6020109	A	01/02/00
				US	5521033	A	28/05/96
WO	9705526	A1	13/02/97	AU	6601996	A	26/02/97
US	5879844	A	09/03/99	JP	9319067	A	12/12/97
				US	6077310	A	20/06/00

BEST AVAILABLE COPY